Site Investigation and Subsurface Boring Logs

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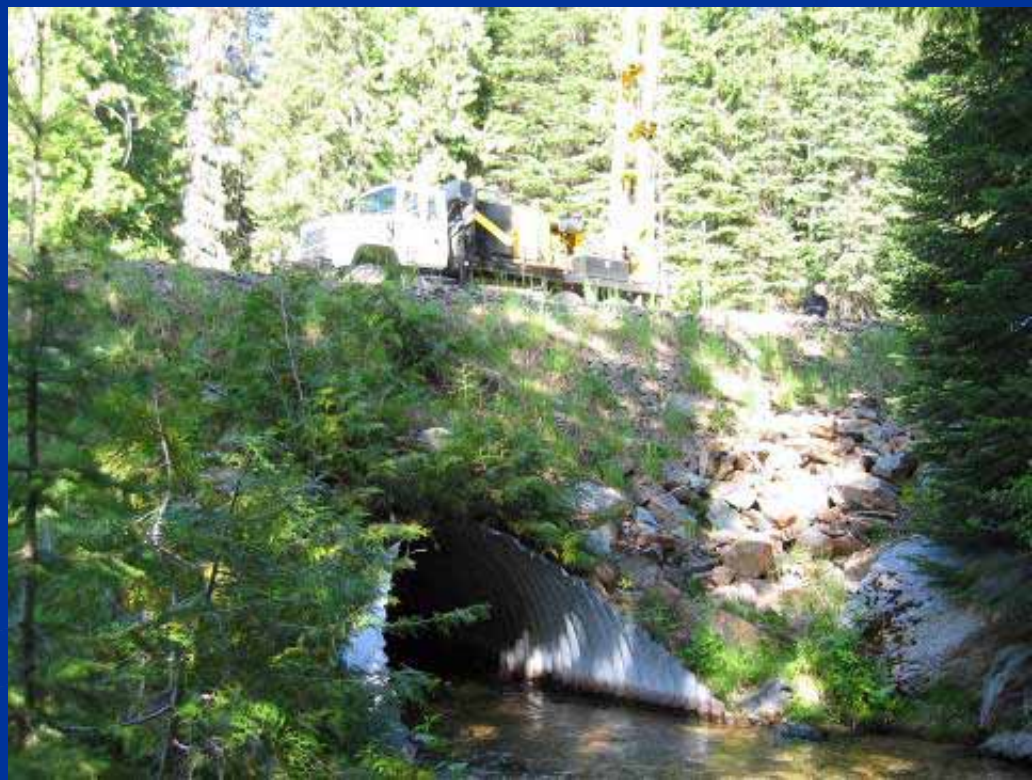
Presentation Outline

- Background
- Field Reconnaissance and Investigation Plan
- Subsurface Investigation
  - Drilling Methods
  - Sampling Techniques
    - SPT
    - Recovery and RQD
  - Instrumentation
- Subsurface Boring Logs

Why Perform a Site Investigation?

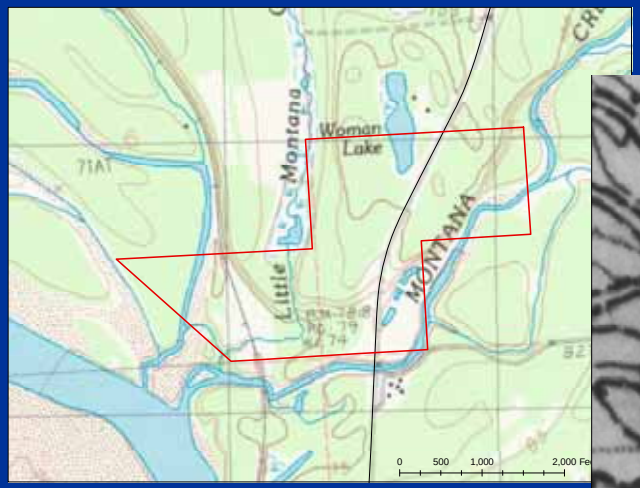
- Gain an understanding of the geology, geologic process, and groundwater at a site and how it impacts a proposed project
- Allows for design and construction of:
  - Cutslopes
  - Embankments
  - Foundations
  - Retaining Walls
  - Pavement Structure
  - Hazard Mitigation
  - Material Sources



- The site investigation, including surface and subsurface exploration, depends on the scope and goal of the project or project element

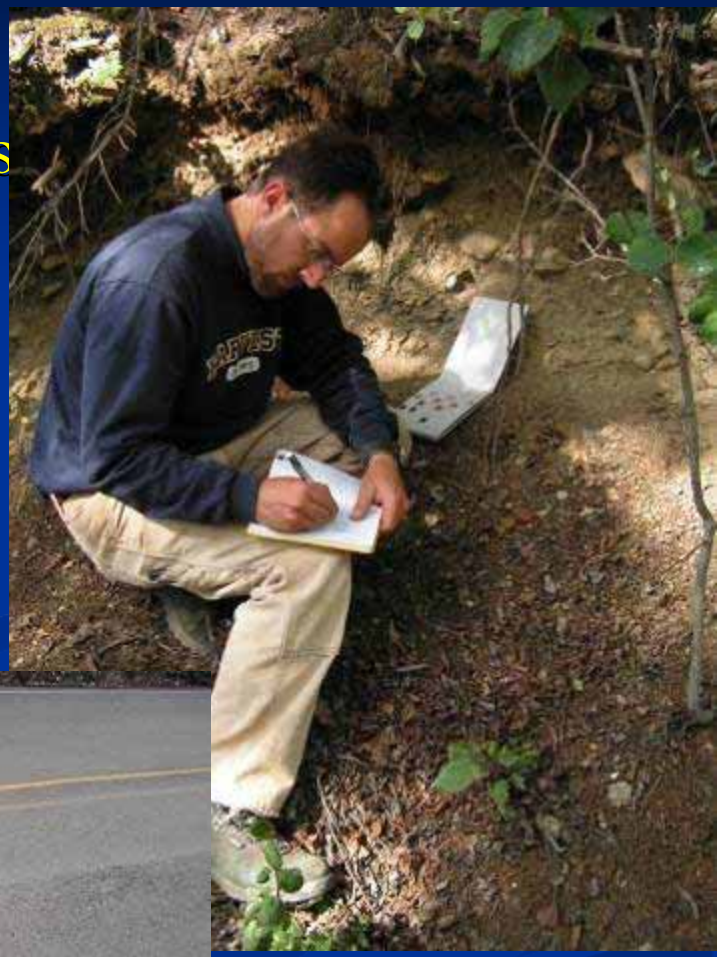
Literature and Map Review

- Topographic Maps
- Geologic Maps
- Soil Survey Maps
- Aerial Photographs
- Other Pertinent Maps and Documents



Field Reconnaissance

- Primary Objectives:
  - Assess geologic surface conditions and geologic processes
  - Expected subsurface conditions
  - Plan subsurface investigation
  - Inspect roadway, retaining wall, bridge foundation, or other structures



Field Reconnaissance

- Additional Objectives:
  - Preliminary material sampling
  - Geologic mapping
  - Slope assessment and rock structure mapping
  - Preliminary cross sections and measurements
  - Surface drainage conditions
  - Groundwater conditions
  - Drilling Access
  - Location of utilities or other impediments to subsurface investigation

Subsurface Investigation Plan

- Location and estimated depth of borings or test pits
- Drilling methods
- Sampling methods
- Access and clearing requirements
- Plan provided to Environment Group for necessary permits
- Drilling contractor or excavator hired and date set for exploration

Table 3-13

Guidelines for minimum number of exploration points and depth of exploration (modified after FHWA, 2002a)

Application	Minimum Number of Exploration Points and Location of Exploration Points	Minimum Depth of Exploration
Retaining walls	(1) A minimum of one exploration point for each retaining wall. (2) For retaining walls more than 100 ft (30 m) in length, exploration points spaced every 100 to 200 ft (30 to 60 m) with locations alternating from in front of the wall to behind the wall. (3) For anchored walls, additional exploration points in the anchorage zone spaced at 100 to 200 ft (30 to 60 m). (4) For soil-nail walls, additional exploration points at a distance of 1.0 to 1.5 times the height of the wall behind the wall spaced at 100 to 200 ft (30 to 60 m).	(1) Investigate to a depth below bottom of wall between 1 and 2 times the wall height or a minimum of 10 ft (3 m) into bedrock. (2) Exploration depth should be great enough to fully penetrate soft highly compressible soils (e.g. peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g., stiff to hard cohesive soil, compact dense cohesionless soil, or bedrock).
Embankment Foundations	(1) A minimum of one exploration point every 200 ft (60 m) (erratic conditions) to 400 ft (120 m) (uniform conditions) of embankment length along the centerline of the embankment. (2) At critical locations, (e.g., maximum embankment heights, maximum depths of soft strata) a minimum of three exploration points in the transverse direction to define the existing subsurface conditions for stability analyses. (3) For bridge approach embankments, at least one exploration point at abutment locations.	(1) Exploration depth should be, at a minimum, equal to twice the embankment height unless a hard stratum is encountered above this depth. (2) If soft strata are encountered extending to a depth greater than twice the embankment height, the exploration depth should be great enough to fully penetrate the soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock).
Cut Slopes	(1) A minimum of one exploration point every 200 ft (60 m) (erratic conditions) to 400 ft (120 m) (uniform conditions) of slope length. (2) At critical locations (e.g., maximum cut depths, maximum depths of soft strata) a minimum of three exploration points in the transverse direction to define the existing subsurface conditions for stability analyses. (3) For cut slopes in rock, perform geologic mapping along the length of the cut slope.	(1) Exploration depth should be, at a minimum, 15 ft (4.5 m) below the minimum elevation of the cut unless a hard stratum is encountered below the minimum elevation of the cut. (2) Exploration depth should be great enough to fully penetrate through soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock). (3) In locations where the base of cut is below ground-water level, increase depth of exploration as needed to determine the depth of underlying pervious strata.

Subsurface Investigation

- Objective
  - Physical description and extent of subsurface materials
  - Sample collection for description and testing
  - Estimation of engineering properties
  - Location of groundwater
  - Installation of monitoring equipment

Subsurface Investigation

- A drill crew typically consists of a driller, a drill helper, and a drill inspector
- The drill inspector is a qualified geologist, engineering geologist, or geotechnical engineer and is responsible for:
  - Drill hole location, depth, and ensuring drilling objectives are met
  - Characterizing and classifying soil and rock material
  - Sample selection and preparation
  - Continually logging the drill hole or test pit
  - Oversight of instrumentation installation

Subsurface Investigation Methods

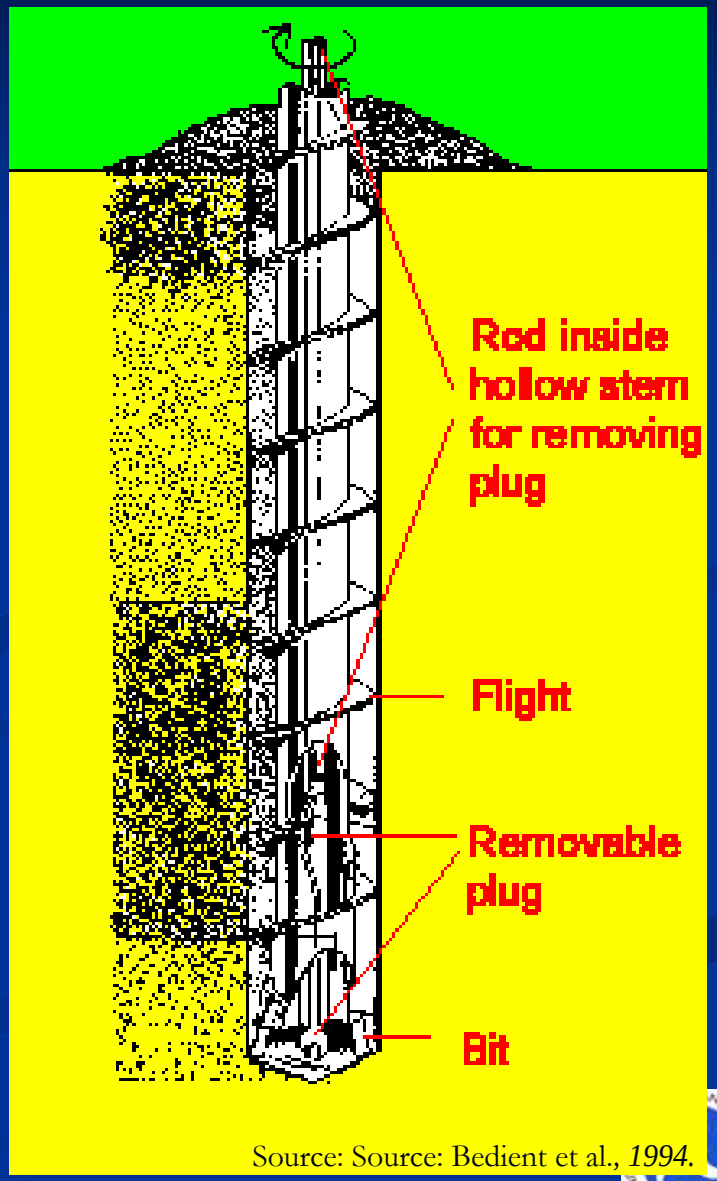
- Drilling Methods
  - Auger
  - Hollow Stem Auger
  - Casing Advancer
  - Wire Line Core
  - Air Rotary
  - Mud Rotary
  - Cable Tool
  - Becker Hammer
  - Sonic
- Other Techniques
  - Backhoe/Excavator Test Pits
  - Hand Probes and Augers
  - Geophysical Methods

Augering

- Used primarily for roadway subgrade investigations
- Typically 5 feet deep
- 14 inches outer diameter solid stem auger
- Material samples collected directly from hole or from auger flight
- Pavement thickness measured directly
- Base, sub-base, and subgrade contacts assessed visually and with driller assistance

Hollow Stem Auger

- Used in unconsolidated materials during general exploration
  - Bridge Foundations
  - Retaining Wall Exploration
  - Cutslopes
  - Landslides
- 8 ¼ inch outer diameter, 4 ¼ inch inner diameter
- Allows sampling tools, instruments, and other devices to be lowered down center of auger



Source: Source: Bedient et al., *1994.*

Casing Advancer

- Used in soil and weak rock during general exploration
  - Bridge Foundations
  - Retaining Wall Exploration
  - Cutslopes
  - Landslides
- Requires drilling fluid
- 3 ½ inch outer diameter, 3 inch inner diameter
- Allows sampling tools, instruments, and other devices to be lowered down center of casing

Triple Barrel Wire Line Core

- Used in rock and other non-augerable materials
- Often used to continue hole after auger/casing advancer refusal
- HQ sized core is 3 ⅞ inch O.D. and 2 ½ I.D.
- Requires water for drilling
- Continuous sampling
- Generally poor to no recovery if not in rock

Test Pits and Trenches

- Fast and inexpensive
- Commonly used for:
  - Locating shallow bedrock
  - Shallow foundation investigation
  - Cutslope investigation
  - Subgrade investigation
  - Muskeg exploration
- Depth limited to extent of equipment or depth hole is able to stay open
- Provides good view of subsurface materials
- Obtain samples of thin critical surfaces

Hand Probes and Augers

- Lightweight
- Portable
- Inexpensive
- Investigation up to 15-20 feet depending on soil type
- Material Densities
- Material Observation/Samples

Intermission


VOLVO

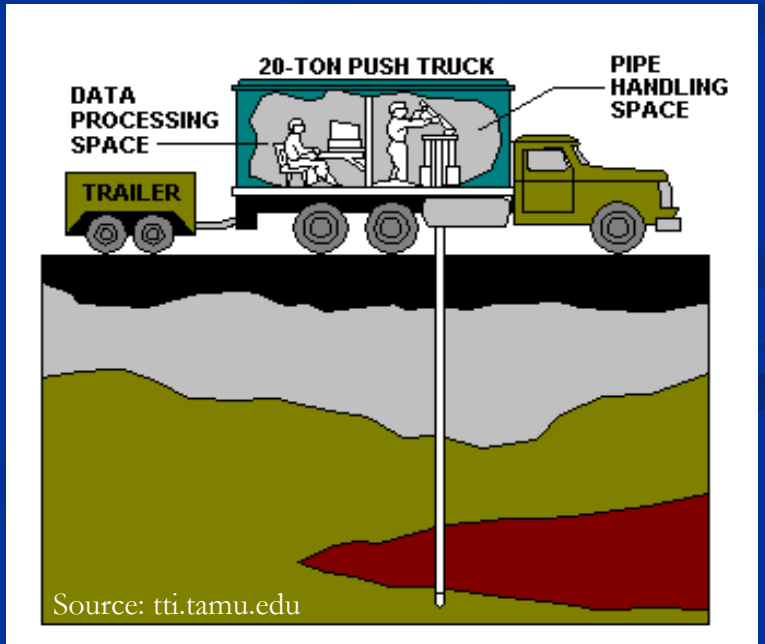

TOYOTA

Material Sampling and In-Situ Tests

- Disturbed Samples
  - Used for index tests
    - Grain Size Analysis, Specific Gravity, Atterburg Limits, Moisture Content (sometimes used for disturbed (residual) strength testing)
- Undisturbed Samples
  - Used for strength, consolidation, and permeability testing
- In-Situ Tests
  - Techniques to test soil and rock materials in the field, primarily for density and/or strength

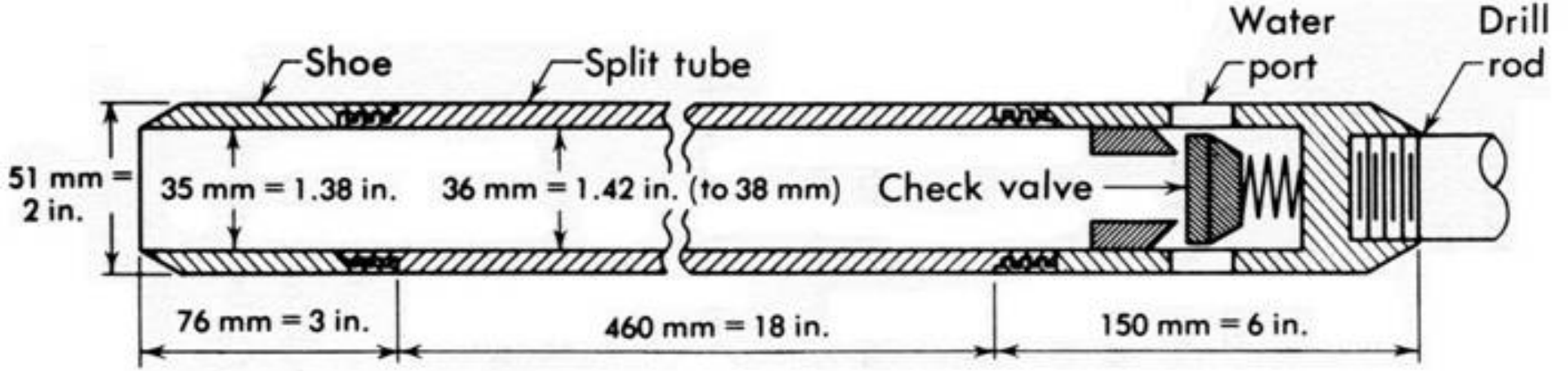
Sampling Methods and In-Situ Tests

- Disturbed Samples
  - Drive Samples, including standard penetration test (SPT)
  - Hand Auger Samples
  - Grab Samples
- Undisturbed Samples
  - Shelby Tube
  - Piston Sampler
  - Denison
  - Pitcher Sampler
- Rock Coring
- In-Situ Tests
  - Standard Penetration Test
  - Cone Penetration Test
  - Pressuremeter Test
  - Dialometer Test
  - Vane Shear Test



Standard Penetration Test (SPT)

- Open ended sampling device driven into soil at specified depth
- Provides disturbed sample of material
- Indication of material density
- ASTM 1586



Standard Penetration Test

- Driven using a 140 lb weight falling 30 inches
  - Blows per 6 inch increment are recorded (10-12-10)
  - Final blow count (SPT N value) is the sum of the blow counts for the final 12 inches (N=22)
  - Refusal is considered 50 blows for less than 6 inches (N = 10-12-50/3")
- Used to estimate soil density, unit weight and material shear strength (chart below)
- Blow counts may be corrected for hammer efficiency and overburden pressure [N to $(N_1)_{60}$]

Estimation of friction angle of cohesionless soils from Standard Penetration Tests (after AASHTO, 2004 with 2006 Interims; FHWA, 2002c)

Description	Very Loose	Loose	Medium	Dense	Very Dense
Corrected SPT $N1_{60}$	0	4	10	30	50
Approximate ϕ, degrees*	25 – 30	27 – 32	30 – 35	35 – 40	38 – 43
Approximate moist unit weight, (γ) pcf*	70 – 100	90 – 115	110 – 130	120 – 140	130 – 150

* Use larger values for granular material with 5% or less fine sand and silt.

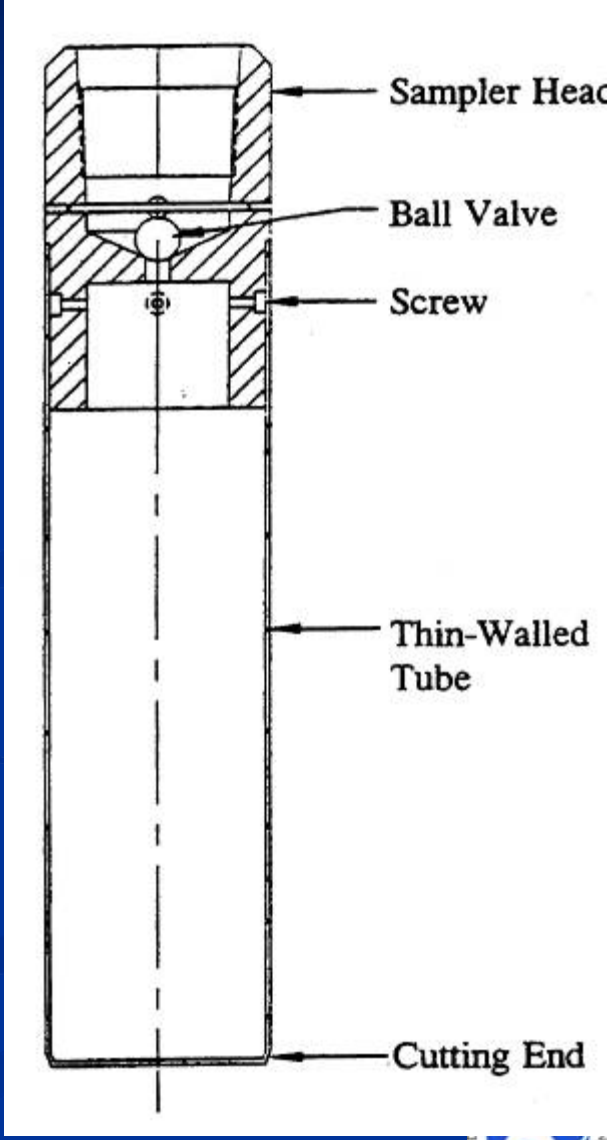
Note: Correlations may be unreliable in gravelly soils due to sampling difficulties with split-spoon sampler as discussed in Chapter 3.

Standard Penetration Test

- Advantages
  - Universal
  - Simple
  - Inexpensive
  - Material sample and density information
- Disadvantages
  - Highly variable and inconsistent
  - Developed for granular materials
  - Very unreliable in cohesive materials
  - Difficult to drive in gravel coarser than about 1.25”

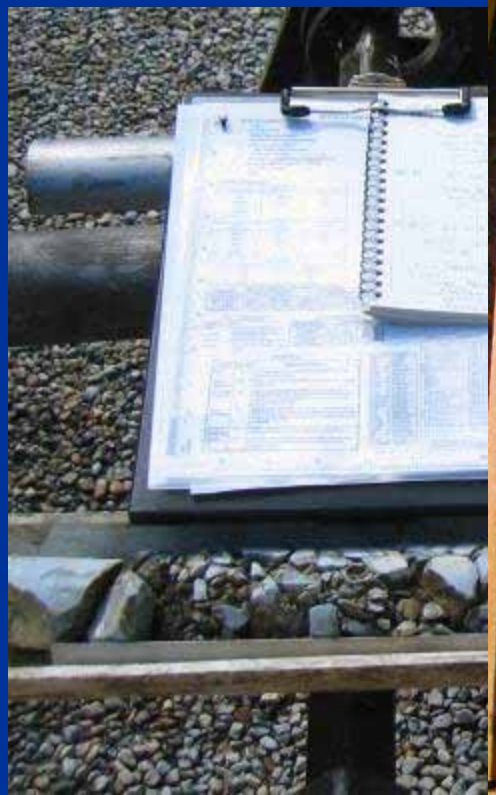
Shelby Tube Sampler

- Used to collect undisturbed samples of cohesive material
- 2 ½ inch O. D., 30 inch long, thin walled metal tube
- Pushed smoothly and rapidly approximately 24 inches into material at a specified depth
- Capped to prevent moisture loss, transported and stored upright, handled carefully to avoid disturbing material



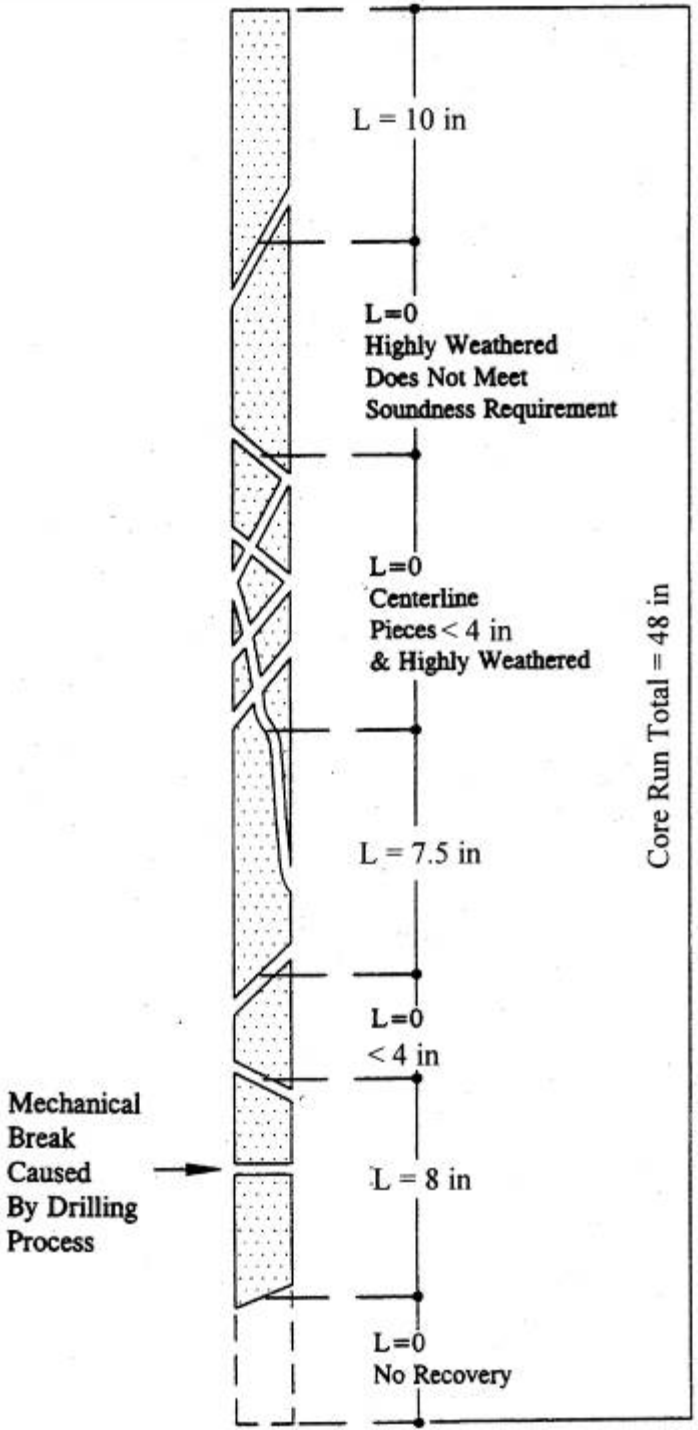
Rock Core

- Sampled using rock coring techniques
- Typically drilled in 5 foot increments called runs (core run lengths may vary)
- Characterized, classified, and logged by drill inspector



Recovery and RQD

- Recovery
  - Core Recovered /Run
  - Rock Quality Designation (RQD)



$$RQD = \frac{\sum \text{Length of Sound Core Pieces} > 4 \text{ in}}{\text{Total Core Run Length}}$$

$$RQD = \frac{10 + 7.5 + 8}{48} \times 100\%$$

RQD = 53% (Fair)

Rock Quality Description

RQD (Rock Quality Designation)	Description of Rock Quality
0 - 25%	Very Poor
25 - 50%	Poor
50 - 75%	Fair
75 - 90%	Good
90 - 100%	Excellent

Recovery and RQD Test

- Core Run: 60 inches

- Recovery (sound pieces):
  - 3 inch piece
  - 15 inch piece
  - 2 inch piece
  - 5 inch piece
  - 3 inch piece
  - 10 inch piece
  - 2 inch piece

- Recovery =

  67%

- RQD =

  50%

Weathering and Strength

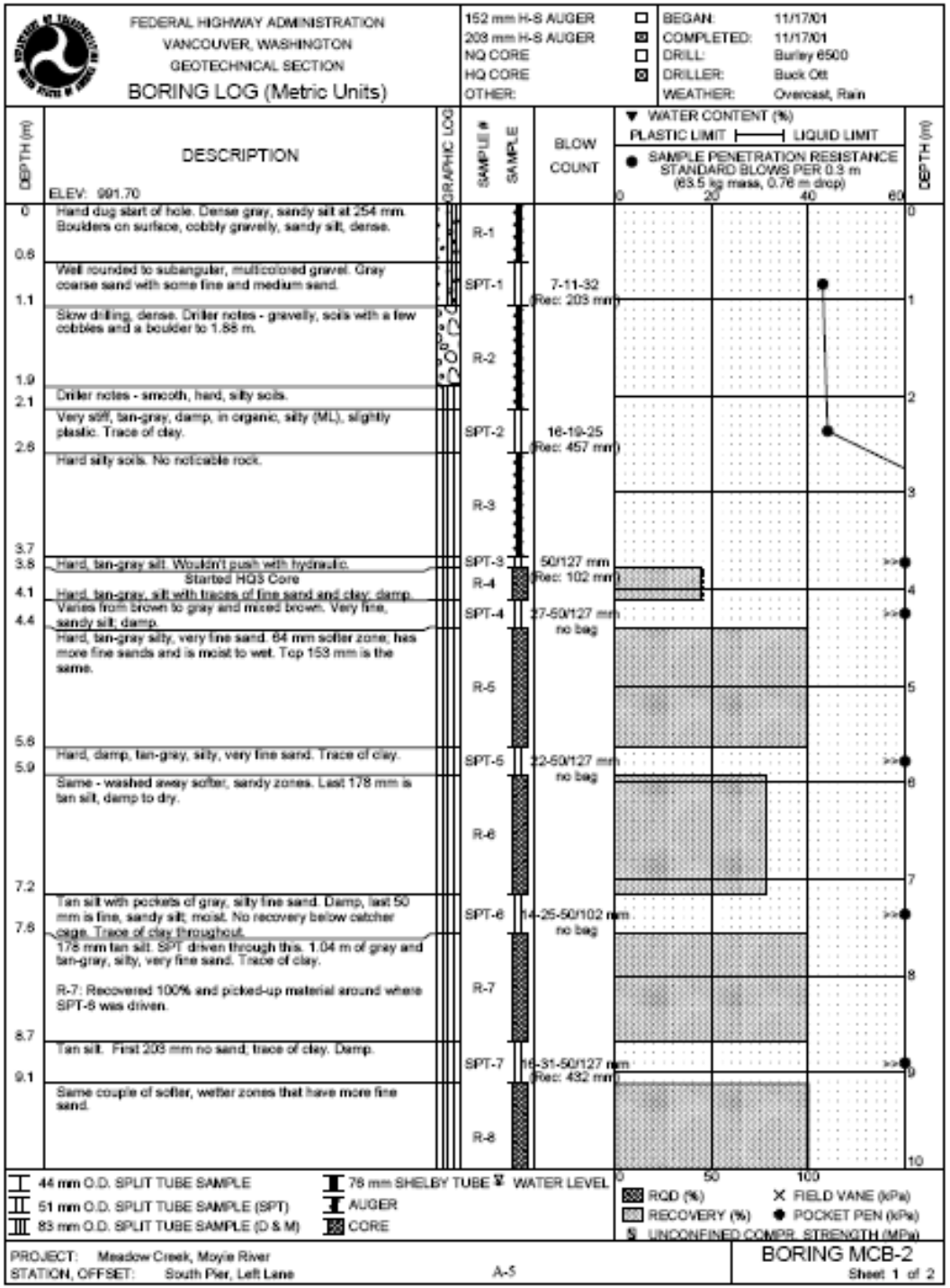
Terms to describe rock weathering and alteration (ISRM, 1981)

Grade (Term)	Description
I (Fresh)	Rock shows no discoloration, loss of strength, or other effects of weathering/alteration
II (Slightly Weathered/Altered)	Rock is slightly discolored, but not noticeably lower in strength than fresh rock
III (Moderately Weathered/Altered)	Rock is discolored and noticeably weakened, but less than half is decomposed; a minimum 2 in (50 mm) diameter sample cannot be broken readily by hand across the rock fabric
IV (Highly Weathered/Altered)	More than half of the rock is decomposed; rock is weathered so that a minimum 2 in (50 mm) diameter sample can be broken readily by hand across the rock fabric
V (Completely Weathered/Altered)	Original minerals of rock have been almost entirely decomposed to secondary minerals even though the original fabric may be intact; material can be granulated by hand
VI (Residual Soil)	Original minerals of rock have been entirely decomposed to secondary minerals, and original rock fabric is not apparent; material can be easily broke by hand
(Extremely Strong Rock)	hammer	(> 250,000)

Instrumentation

- Movement
  - Inclinometers
  - Extensometers
  - Tiltmeters
  - Strain Gages
- Settlement/Pressures
  - Settlement Cell
  - Load/Pressure Cells
  - Extensometers
- Groundwater Levels
  - Piezometers

Boring Logs



FEDERAL HIGHWAY ADMINISTRATION
VANCOUVER, WASHINGTON
GEOTECHNICAL SECTION
BORING LOG (Metric Units)

152 mm H-S AUGER ☐
203 mm H-S AUGER ☒
NQ CORE ☐
HQ CORE ☒
OTHER:

BEGAN: 11/17/01
COMPLETED: 11/17/01
DRILL: Burley 6500
DRILLER: Buck Ott
WEATHER: Overcast, Rain

DEPTH (m)	DESCRIPTION (ELEV: 991.70)	SAMPLE #	BLOW COUNT
0	Hand dug start of hole. Dense gray, sandy silt at 254 mm. Boulders on surface, cobbly gravelly, sandy silt, dense.	R-1	
0.8	Well rounded to subangular, multicolored gravel. Gray coarse sand with some fine and medium sand.	SPT-1	7-11-32 (Rec: 203 mm)
1.1	Slow drilling, dense. Driller notes - gravelly, soils with a few cobbles and a boulder to 1.88 m.	R-2	
1.9	Driller notes - smooth, hard, silty soils.		
2.1	Very stiff, tan-gray, damp, in organic, silty (ML), slightly plastic. Trace of clay.	SPT-2	16-19-25 (Rec: 457 mm)
2.6	Hard silty soils. No noticable rock.	R-3	
3.7			
3.8	Hard, tan-gray silt. Wouldn't push with hydraulic. Started HQ3 Core	SPT-3	50/127 mm (Rec: 102 mm)
4.1	Hard, tan-gray, silt with traces of fine sand and clay; damp.	R-4	
4.4	Varies from brown to gray and mixed brown. Very fine, sandy silt; damp.	SPT-4	27-50/127 mm no bag
	Hard, tan-gray silty, very fine sand. 64 mm softer zone; has more fine sands and is moist to wet. Top 153 mm is the same.	R-5	
5.8			
5.9	Hard, damp, tan-gray, silty, very fine sand. Trace of clay.	SPT-5	22-50/127 mm no bag
	Same - washed away softer, sandy zones. Last 178 mm is tan silt, damp to dry.	R-6	
7.2			
7.6	Tan silt with pockets of gray, silty fine sand. Damp, last 50 mm is fine, sandy silt; moist. No recovery below catcher cage. Trace of clay throughout.	SPT-6	14-25-50/102 mm no bag
	178 mm tan silt. SPT driven through this. 1.04 m of gray and tan-gray, silty, very fine sand. Trace of clay.	R-7	
	R-7: Recovered 100% and picked-up material around where SPT-6 was driven.		
8.7	Tan silt. First 209 mm no sand; trace of clay. Damp.	SPT-7	16-31-50/127 mm (Rec: 432 mm)
9.1	Same couple of softer, wetter zones that have more fine sand.	R-8	

WATER CONTENT (%)
PLASTIC LIMIT ⊢ LIQUID LIMIT
● SAMPLE PENETRATION RESISTANCE STANDARD BLOWS PER 0.3 m (63.5 kg mass, 0.76 m drop)
0 20 40 60

0 50 100
RQD (%)
RECOVERY (%)
UNCONFINED COMPR. STRENGTH (MPa)
× FIELD VANE (kPa)
● POCKET PEN (kPa)

44 mm O.D. SPLIT TUBE SAMPLE
51 mm O.D. SPLIT TUBE SAMPLE (SPT)
83 mm O.D. SPLIT TUBE SAMPLE (D & M)
78 mm SHELBY TUBE
AUGER
CORE
WATER LEVEL

PROJECT: Meadow Creek, Moyie River
STATION, OFFSET: South Pier, Left Lane

A-5

BORING MCB-2
Sheet 1 of 2

Top and Bottom Sections

FEDERAL HIGHWAY ADMINISTRATION
VANCOUVER, WASHINGTON
GEOTECHNICAL SECTION

BORING LOG (English Units)

6 in H-S AUGER	☐	BEGAN:	10/11/06
8 in H-S AUGER	☒	COMPLETED:	10/13/06
NQ CORE	☒	DRILL:	CME-45
HQ CORE	☐	DRILLER:	Gary Cormier
OTHER:		WEATHER:	Light rain, 44° F

DEPTH (ft)	DESCRIPTION	GRAPHIC LOG	SAMPLE #	SAMPLE	BLOW COUNT	WATER CONTENT (%) / PLASTIC LIMIT — LIQUID LIMIT / SAMPLE PENETRATION RESISTANCE BLOWS PER FOOT (140 lb mass, 30 in drop)	DEPTH (ft)
0	ELEV: 23 ft. (7 m) Loose, brown, silty, sandy GRAVEL and COBBLES with some boulders and a trace of clay, damp (GW) (Talus)		R-1			0 20 40 60	0
							2
			MC-1		8-3-7 (Rec: 2in)		4
			R-5		(Rec: 7in)		20
	Auger grinding on boulder. Refusal at 20'.						

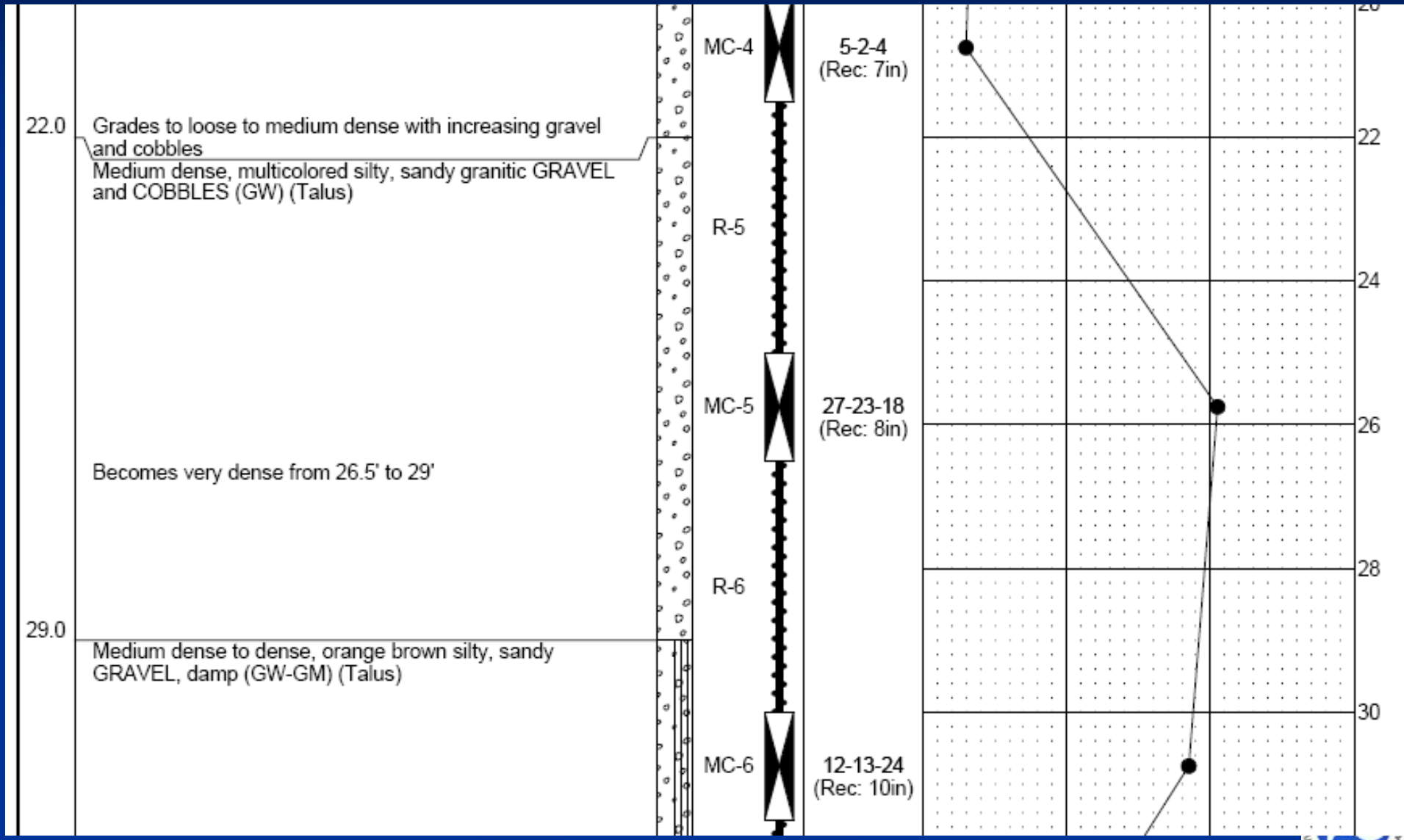
1.75 in O.D. SPLIT TUBE SAMPLE
2 in O.D. SPLIT TUBE SAMPLE (SPT)
2.5 in O.D. MOD. CA SAMPLER (MC)
1 5/8" Drive Test
AUGER
CORE
WATER LEVEL

0 50 100
RQD (%)
RECOVERY (%)

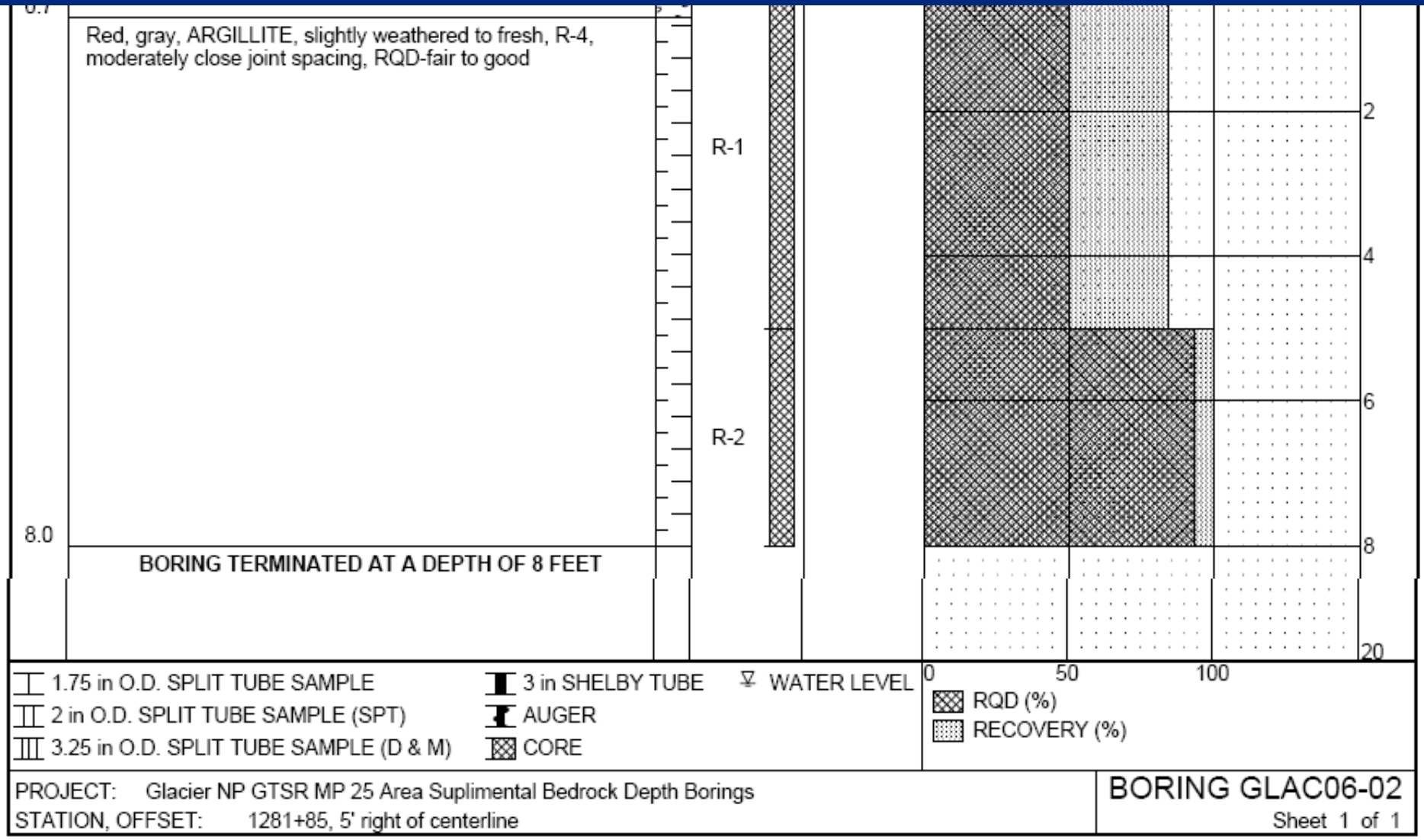
PROJECT: Walden Point Road Retaining Wall
STATION, OFFSET: 0+375, 5 m R, 37.5 ft. from center of pipeline, 42 ft. from rock at ground level

BORING WPR06-1
Sheet 1 of 3

Example Log in Soil Material



Example Log in Rock




Questions?